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Fence Characterization for Intrusion Detection Systems

Michael R. Walsh and Lindamae Peck

May 1990

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For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Special Report 90-18

U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Fence Characterization for Intrusion Detection Systems

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May 1990

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Michael R. Walsh, Mechanical Engineer, of the Engineering and Measurement Services Branch, Technical Services Division, and Dr. Lindamae Peck, Geophysicist, of the Geophysical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by DA Project 4A762784AT42, *Design, Construction and Operations Technology for Cold Regions*, Task BS, Work Unit 006, *Cold Regions Effects on Intrusion Detection Systems*.

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The authors thank James S. Morse and Frederick Crory of CRREL and S. Willoughby of the U.S. Army Corps of Engineers, Huntsville Division, for technical reviews of this report and many helpful comments. Rae Melloh and Gary Trachier participated as fence climbers. Fred Gernhard did the custom fabrication of some of the equipment.

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Fence Characterization for Intrusion Detection Systems

MICHAEL R. WALSH AND LINDAMAE PECK

INTRODUCTION

While conducting research on intruder-intrusion detection system (IDS) interaction and response, it became apparent to CRREL personnel that the condition of the chain-link fence was critical not only to the validity of the data but to the repeatability of the results. A search of the current literature and canvassing of individuals responsible for installation and acceptance of fence-mounted intrusion detection systems revealed that no equipment or standard operating procedure existed for obtaining or comparing fence characteristics in a quantitative manner. For these reasons, development of equipment and a method for quantitatively obtaining data for fence characterization was initiated.

The characteristic parameters of a fence that are important for the proper operation of a fence-mounted IDS are the post rigidity, the post plumbness, and the normal and transverse stiffness of the fence fabric. The stiffness parameters refer to resistance to deflection in directions perpendicular and parallel, respectively, to the fence fabric. These parameters not only affect the operability of the IDS but also are good indicators of the integrity of the fence itself. Therefore, they are applicable whether an IDS is installed or not.

An intrusion detection system is, for the case of this report, an electronic system that is integral with or mounted on the fence and has the expressed purpose of detecting an intruder as he cuts or climbs the fence. The IDS response to such an attempt would be to notify security personnel via visual and/or audible alarms.

This report outlines procedures for obtaining numerical values for various fence parameters that will enable the security officer or facilities engineer to gather data upon which to make judgments on the integrity of the IDS involved. Instrumentation developed for this task is described and the results are presented of the use of this instrumentation to characterize three chain-link fences that differ in construction and age. All the fence parameters are expected to show an overall dependence on the construction, maintenance, and age of the fence, and perhaps a daily or seasonal dependence on factors such as temperature and the occurrence of frost heaving and thawing ground.

APPLICATIONS

Security officers who encounter performance problems (too low a probability of detection, too high an occurrence of nuisance or false alarms) with a fence-mounted IDS currently have no reliable means of isolating the condition of the fence from the many other factors, such as the environment and IDS installation and maintenance, that affect IDS performance. In comparing their experiences with a particular IDS to those of other security personnel, they must contend with subjective, qualitative descriptions of the fences involved. The establishment of standard techniques and equipment for characterizing a chain-link fence replaces ambiguous qualitative assessments with quantitative measurements of critical parameters.

A record of the parameters characterizing the perimeter fence at a facility can be analyzed for changes as the fence ages or is modified, and for correlation between zonal differences in IDS performance and corresponding variations in fence quality. If the fence parameters at several facilities have been quantified in a standard manner, then the successes and failures of IDSs in joint use can be evaluated relative to the condition of each facility's fence. Finally, the establishment of a central data base of fence parameters and IDS performance will assist security designers in selecting the IDS for a facility. For example, if review of the data base reveals that the detection capability of a particular IDS is unacceptable when the deflection of the fence fabric in response to a standard load is above a critical value (or perhaps, below a critical value), then installa-

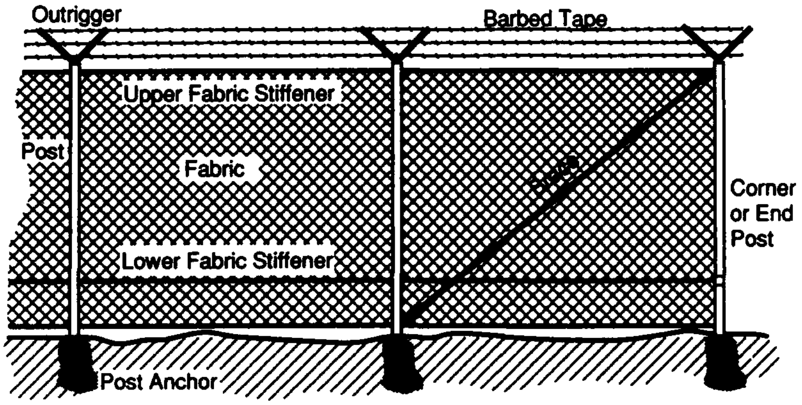


Figure 1. Components of fence. Type and location of stiffeners vary among fences.

tion of that IDS will not be recommended for facilities with existing fences that do not meet the criteria for optimum performance of the IDS. Should a substitute IDS not be available, then the need to improve the existing fence, and the consequent expense, can be incorporated in the IDS design plan.

A standard procedure for characterizing chain-link fences will also have application in determining whether a newly installed fence meets acceptance criteria irrespective of an IDS. Specifications for fence installation with regard to suitability of use with an IDS could be developed.

FENCE TERMINOLOGY

A fence system is generally composed of posts (line and terminal), stiffeners, braces, anchors, fabric, outriggers, and barbed tape or wire (Fig. 1) The posts and anchors are self-explanatory. The stiffeners run horizontally either through or attached to the fence fabric, the wire mesh of the fence. Common stiffeners are 38-mm diameter galvanized pipe and 4.6-mm diameter galvanized wire. Stiffeners are used at some or all of these locations on the fence fabric: top, bottom, and at intervals (often every 0.6 m with a 2.4-m (8-ft) fence). In some instances, the bottom of the fabric is set in a concrete sill, thus eliminating the need for the bottom stiffener. Braces of pipe run diagonally or horizontally and are used to strengthen the terminal posts, which are located at corners or gates. Outriggers and barbed tape or barbed wire are located at the top of the fence. The outriggers attach to the post tops while the barbed tape or wire attaches to the outriggers. A panel is the area of fence fabric located between posts; it is a common term used in characterizing fences. For a complete listing of terms and definitions related to fencing, see ASTM F 552-88b (1989).

PARAMETER VALUES

Target values for 3 of the 4 parameters (normal stiffness, transverse stiffness, post rigidity, post plumbness) are given in Table 1. The values for the normal fabric stiffness and post rigidity came from AFSC (1985) and information provided by Basil Steele, Sandia National Laboratories. Transverse stiffness does not have a value but is a relationship; the links are not supposed to separate below a given value (118 N). This value is not a standard, but rather a common usage value derived through experience by various people involved in the inspection of fences. Therefore, this value should not be used solely to reject a fence but should be used as supplementary data in arriving at a decision as to the quality of a fence and its suitability for a fence-mounted IDS. At present there is no standard for plumbness of a fence post; it is hoped that, as characterization data on a variety of chain-link fences become available, a suitable criterion for post plumbness will be identified.

Table 1. Standard test loads and resultant displacements for fence characterization.

Test	*Applied force*	*Acceptable displacement*
Fabric–normal	132 N	75 mm
Fabric–transverse	118 N	None*
Post–rigidity	226 N	20 mm†/0.7°

*Secondary (non-critical) values.
†Over a vertical distance of 1.5 m.

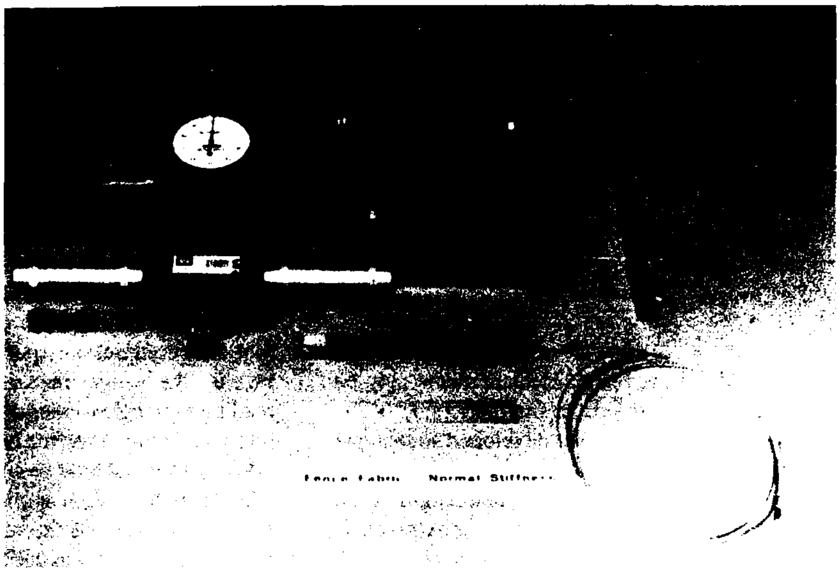


Figure 2. Normal stiffness equipment: fabric side. Ruler in foreground indicates scale.

MEASUREMENT EQUIPMENT AND TECHNIQUES

Perhaps the most obvious parameter that needs to be measured is the normal stiffness of the fence fabric. The normal stiffness is tested in the center of a panel, usually the weakest area of a panel due to the distance from the fence components (posts, stiffeners) that help immobilize the fabric. If a stiffener runs through the center of the panel, which significantly stiffens the fabric in that area, the fabric should be tested between the center stiffener and an adjacent stiffener. The fabric should be tested midway between posts, in either case. The effectiveness of whatever stiffeners are in place is evident in the variation of normal stiffness with location on the fence panel.

Figure 2 shows the prototype equipment developed at CRREL for testing normal stiffness on the fabric side of the fence, and Figure 3 shows the prototype equipment developed at CRREL for testing normal stiffness

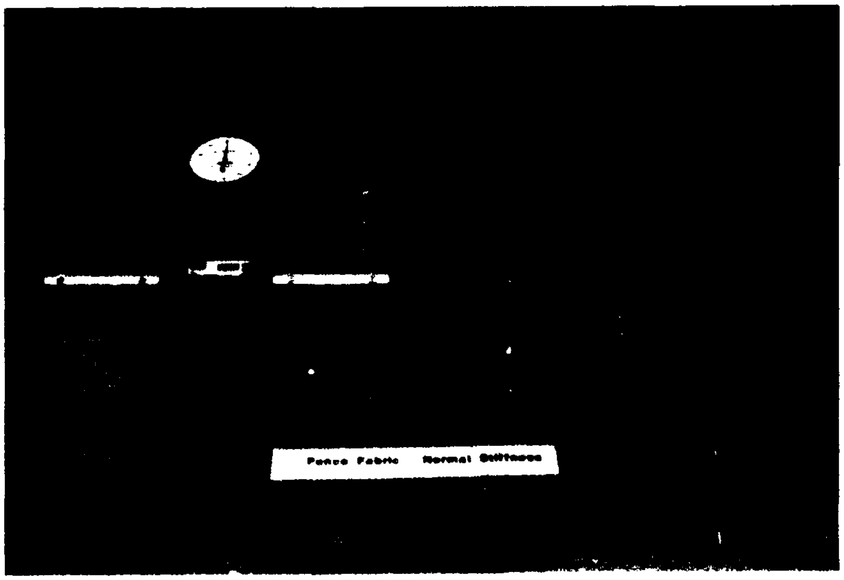


Figure 3. Normal stiffness equipment: post side. Ruler in foreground indicates scale.

Table 2. Test equipment for measuring the normal stiffness of the fence fabric.

Fabric side	*Post side*
Force gauge	Force gauge
Plumb-bob and line	Plumb-bob and line
Scale	Scale
Clamp-on standoff	Magnetic base and post

on the post side of the fence. Measurements may be made on either the post side or the fabric side of the fence. The two techniques were developed so that one person working between double fencing could test both fences as he or she proceeded down their length. A list of the equipment shown in these figures is given in Table 2. Only the equipment for holding the plumb-bob line (gauge line) in place is unique to the side of the fence being tested.

After a suitable location for testing the panel is located, the fabric is exercised using the tension/compression force gauge shown in Figures 2 and 3. A 226-N (51-lbf) force is applied in the two normal directions (push, pull) of the panel. This is repeated for a total of four displacements. By exercising each panel prior to measuring deflections, a common short-term stress history is imparted to all the panels. Since panels "give" and subsequently recover to some extent, exercising the panels is an attempt to minimize bias in the measurements due to nonuniform prior loading of the fence. A gauge line is then positioned between posts located at either end of the panel and the displacement scale attached onto the fence so that the scale lies lightly atop or just below the gauge line (see Fig. 4 for fabric-side setup, Fig. 5 for post-side setup). Figure 6 shows the gauge/scale area during a tension test. Displacement of the fence fabric under load relative to the gauge line is determined from the before and after readings of the position of the gauge line at the scale. The test of normal stiffness is performed in either tension (pulling the fabric) or compression (pushing the fabric). When setting up the gauge line, sufficient room to obtain a reading must be provided. As the maximum acceptable fabric deflection is on the order of 75 mm (3 in.), about 100 mm (4 in.) should be sufficient (Fig. 7). A force of 132 N (30 lbf) is then applied normal to the fabric and the displacement of the scale (attached to the fence fabric) relative to the gauge line (stationary) is recorded.

A second parameter associated with the fence fabric is the transverse stiffness. As with the normal stiffness, transverse stiffness is measured in the center of a panel. The transverse stiffness should be measured both vertically and horizontally. For transverse stiffness tests, a single piece of equipment, shown in Figure 8, is used. On the bottom of the mechanism are a disk and a hook. The disk is inserted through a link in the fence panel and the device oriented in the correct direction (horizontal or vertical). The wheel is then turned until the hook engages a second link. The wheel is turned slowly until the scale indicates 118-N (26-lbf) applied force while

Figure 4. Normal stiffness setup: fabric side.

Figure 5. Normal stiffness setup: post side.

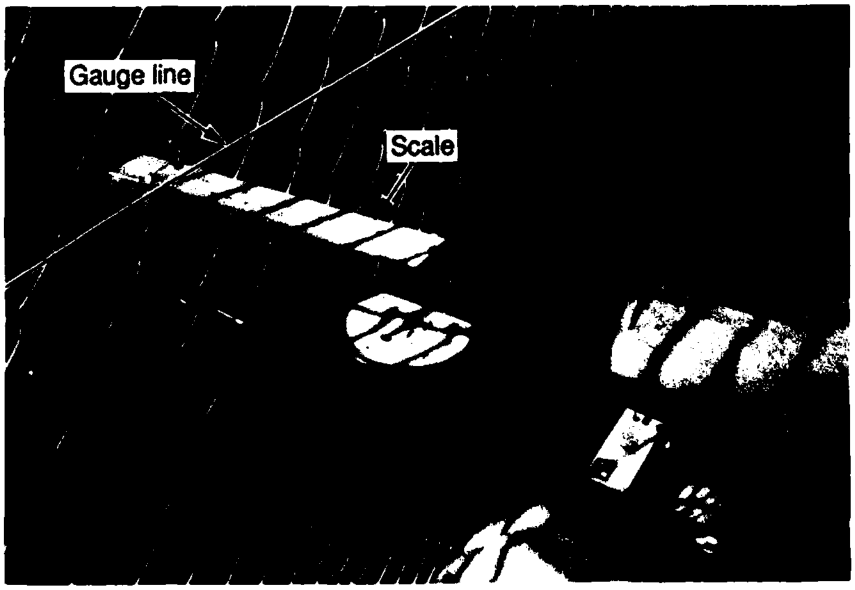


Figure 6. Reading normal stiffness deflection. Gauge line and scale are marked. Deflection of the fence fabric displaces the scale relative to the stationary gauge line. The deflection of the fabric is the difference between the gauge-line positions (before, after) on the scale.

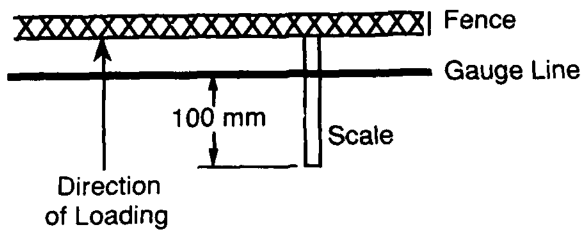


Figure 7a. Proper positioning (top view) of gauge line and scale for compression tests of normal stiffness.

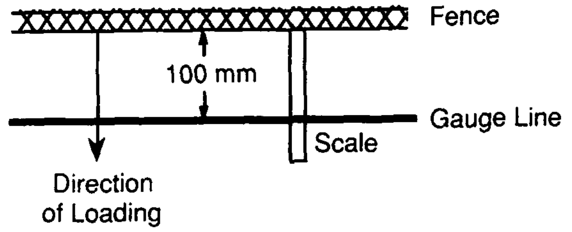
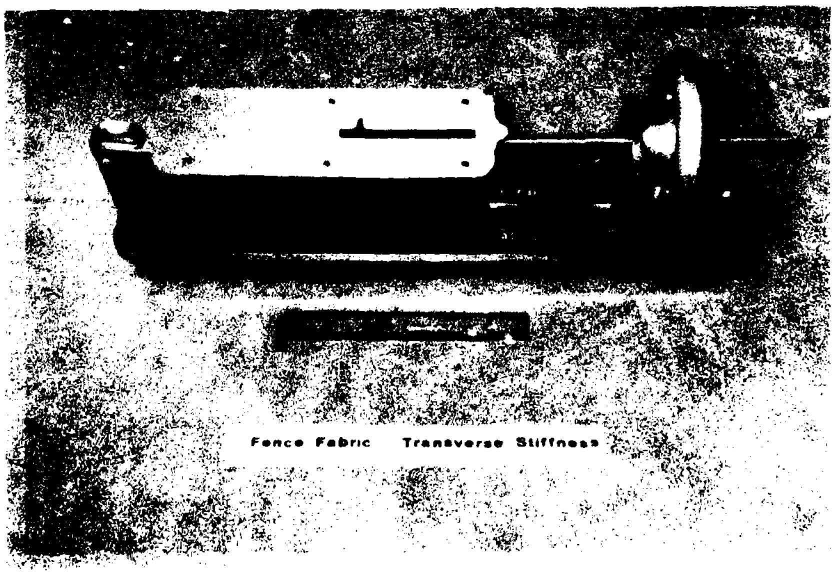


Figure 7b. Tension tests of normal stiffness.



a Equipment. Ruler in foreground indicates scale.

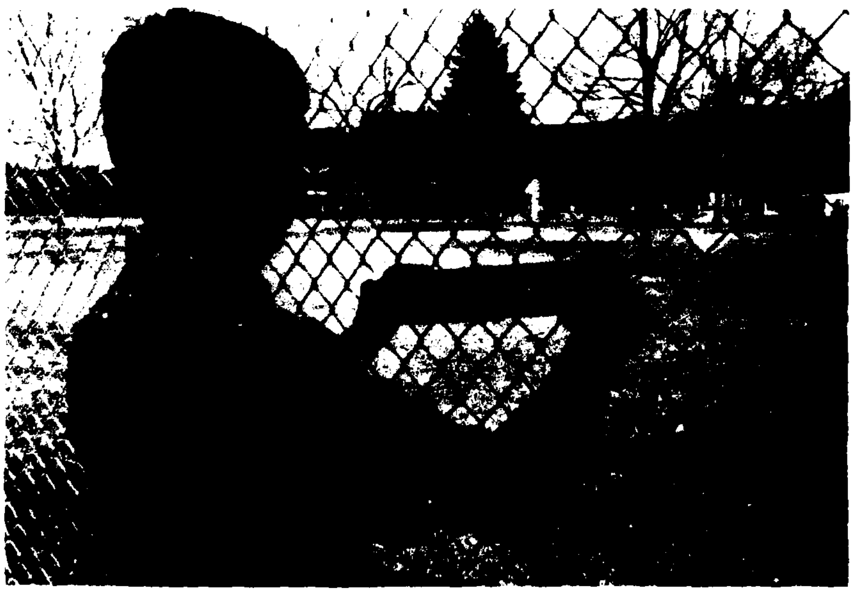
Figure 8. Determination of transverse stiffness.

the links spanned by the device are checked for separation. If the links separate before the 118-N limit, the force is recorded and the applied force released; otherwise, the panel in this location has passed the test.

Post rigidity is an important aspect in the proper functioning of a fence and an IDS. Weak or improperly anchored posts will allow movement of the fence and may cause nuisance alarms from the IDS. In addition, weak posts or bad anchors may allow easier breaching of the fence by an intruder. To measure post rigidity, a force gauge and plumb-bob can be used. Tests are conducted by applying a 226-N (51-lbf) force perpendicular to the post at a height of 1.5 m (5 ft). Deflection is then measured at the bob (near ground level). An alternative method would be to use a digital protractor in place of the plumb-bob (Fig. 9). The inclination of the post is read from the digital protractor and recorded. An estimate of the deflection of the post can then be calculated from the angle and distance to the ground. The movement of poorly anchored posts can bias the measurements of normal stiffness of the fence fabric. The plumb-bob method or the digital protractor should be used consistently because the digital protractor gives a localized measurement while the plumb-bob averages deflection over the length of the bob line.

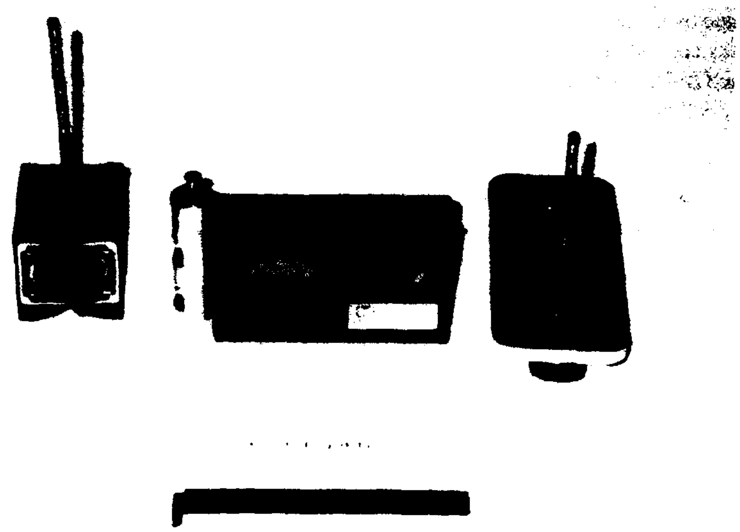
A final factor to be considered is post plumbness. Although not critical to the suitability of the fence for an IDS, it is an indication of the condition of the fence and therefore the integrity of the IDS. Fence plumbness is measured in the direction normal to the panels at the posts. Corner posts require characterization in directions perpendicular to each panel. Two methods can also be employed to accomplish this. In the first, a digital protractor attached at an elevation of 1.5 m (5 ft) can be used to directly obtain tilt in degrees. Care must be exercised to ensure the correct zero value on the digital protractor. In the second method, a plumb-bob is hung from a height of 1.5 m (using either the clamp-on standoff or the magnetic base and post) and the bob stabilized near the ground level (Fig. 10a,b). Three horizontal distances are then measured: at the top, halfway down, and near the bottom. The three data points give an indication of the linearity of the tilt. Using only the top and bottom figures is normally sufficient. The angle of tilt can then be calculated from the vertical distance and the reduced (maximum – minimum) horizontal distance. Any bend or bowing of the fence post may contribute to the measurements of apparent plumbness and should be noted.

The above sections on measuring post rigidity and post plumbness consider only measurements made perpendicular to the fabric, because that is the dominant detectable orientation of the loading that an intruder climbing the fence would impart to the posts. The techniques apply equally well to measurements of post rigidity and plumbness in a direction parallel to the fence fabric. Post plumbness may vary with orientation, but post rigidity is not expected to be directional if the post is set in concrete that is firmly anchored in the ground.



b. Using the transverse stiffness equipment.

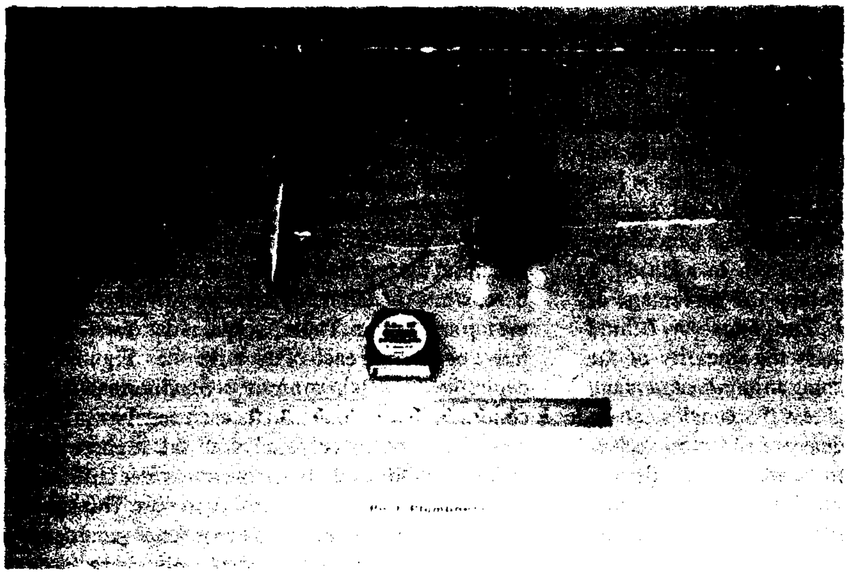
Figure 8 (cont'd). Determination of transverse stiffness.



a. Digital protractor and supports for post or fabric sides.

b. Digital protractor attached to fence post and load applied.

Figure 9. Post rigidity equipment.



a. Equipment (plumb bob kit). The magnetic clamp holds the plumb line offset from the post. Distances between the plumb line and the post along its length are measured with the tape. Ruler in foreground indicates scale.

b. Using the post plumbness equipment.

Figure 10. Determination of post plumbness (plumb bob kit).

STANDARD TEST AND EVALUATION PROCEDURE

The development of a standard procedure was broken down into two categories, qualitative (visual) and quantitative. As the categories imply, the first is less rigorous and time consuming than the second. Appendix A contains a general outline of the procedures involved in both types of inspection. In addition, a frequency of inspection, including the percentage of fence to be inspected, is given. The philosophy behind these procedures is to maintain the integrity of the security system without consuming an inordinate amount of manpower. Inspection and test frequencies can be varied, depending on locally determined factors such as the degree of security desired as well as the climatic wear and tear on the system. For instance, in cold climates, frost heaving may affect post plumbness, and post rigidity would be highest in frozen or dry soil and lowest during thawing of the ground. Thus, where seasonal variation occurs, these parameters should be checked more frequently than specified. The requirements of a specific IDS may also require more frequent inspection of a fence to avoid nuisance alarms. In any case, the outline presented in Appendix A is proposed as a minimum general inspection procedure of a fence.

FIELD TESTING OF EQUIPMENT

The fence characterization equipment developed at CRREL has been evaluated on three different fences. The first is a recently installed (1988) perimeter fence surrounding CRREL. The second is a section of older, unmaintained fence that borders a section of CRREL. The age of this section is unknown but is thought to be at least 10 years. The third fence, erected in 1987, is located at the Geophysical Sensors Cold Regions Research Facility in South Royalton, Vermont, as part of the SOROIDS (South Royalton Intrusion Detection Systems) Project. The posts of all three fences are anchored in concrete. The SOROIDS fence has five wire stiffeners: one each at the top and bottom of the fence, and the remaining three equally spaced between. The new CRREL fence has a 38-mm-diameter pipe located at the top of the fence and a wire stiffener at the base, while the old fence has wire stiffeners located at the top and bottom. Table 3 contains data for a representative panel from each of the three sites. Figures 11–13 depict these panels in an unstressed and normally stressed condition. The normal load for each panel was 132 N, as specified. The fence panel with the highest normal stiffness (SOROIDS) failed the transverse stiffness test and was supported by the least rigid post. This substantiates the need to measure all four fence parameters to establish a data base that adequately characterizes a fence.

SOROIDS fence

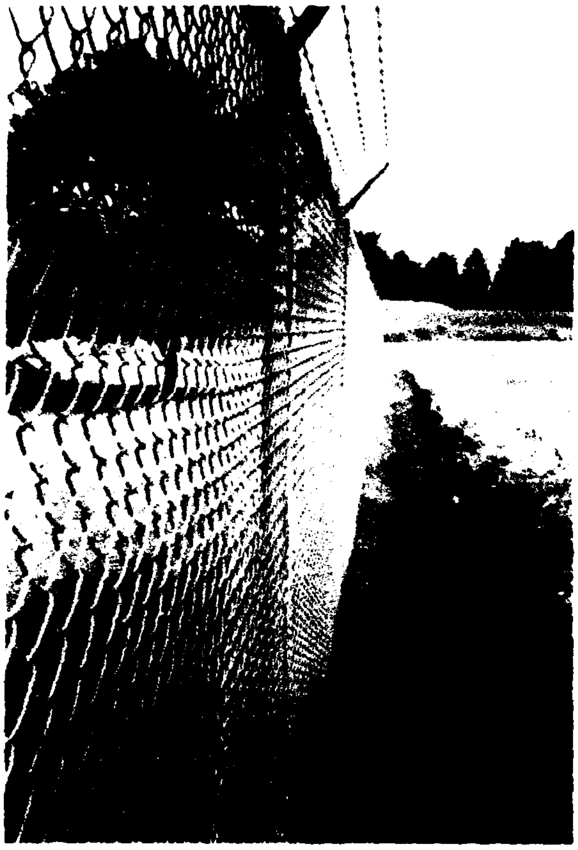
To test the variability of fence characteristics, the inner security fence at SOROIDS was characterized. Figure 14 shows the facility, with the inner fence being nearest to the instrumentation and storage buildings. The significant features of the inner fence are two braced ends, a corner, a 42-m east–west section, and a 150-m north–south section. The method was to test the two adjacent panels at each fence end, the four panels nearest the corner (two on each side), and every fifth panel in between.

Since the inner section is outfitted with a commercial IDS that is intended to alarm when the fence is cut or climbed, the data collected could be employed for two purposes: to quantify the fence characteristics for use in evaluating the IDS and to verify the use of the fence

Table 3. Parameter values for three test panels.

Fence location	Fabric: Normal displacement*	Fabric: Transverse stiffness† Horizontal	Fabric: Transverse stiffness† Vertical	Post: Plumbness angle	Post: Rigidity**
CRREL (Old)	78 mm	(118)	(118)	0.5°	0.6 mm
CRREL (New)	77 mm	(118)	(118)	0.3°	3.0 mm
SOROIDS	76 mm	39 N	98 N	0.2°	4.0 mm

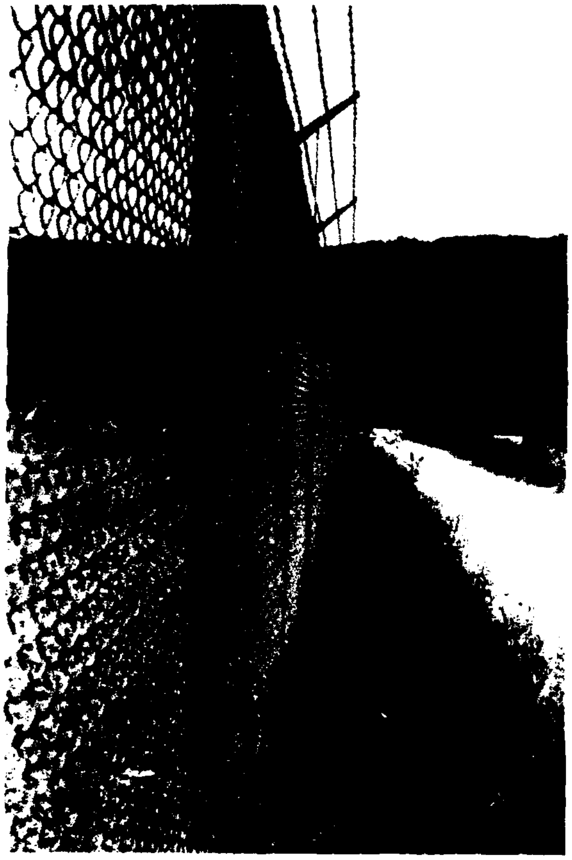
*132 N applied load.
**226 N applied load.
†For transverse stiffness, a value indicates the load (up to 118 N) at which link separation occurs; (118) denotes no separation at 118 N transverse load.



◀ *a. Prior to normal loading.*

b. Under 132-N normal (pull) load. ▶

Figure 11. New CRREL fence.



◀ *a. Prior to normal loading.*

b. Under 132-N normal (pull) load. ▶

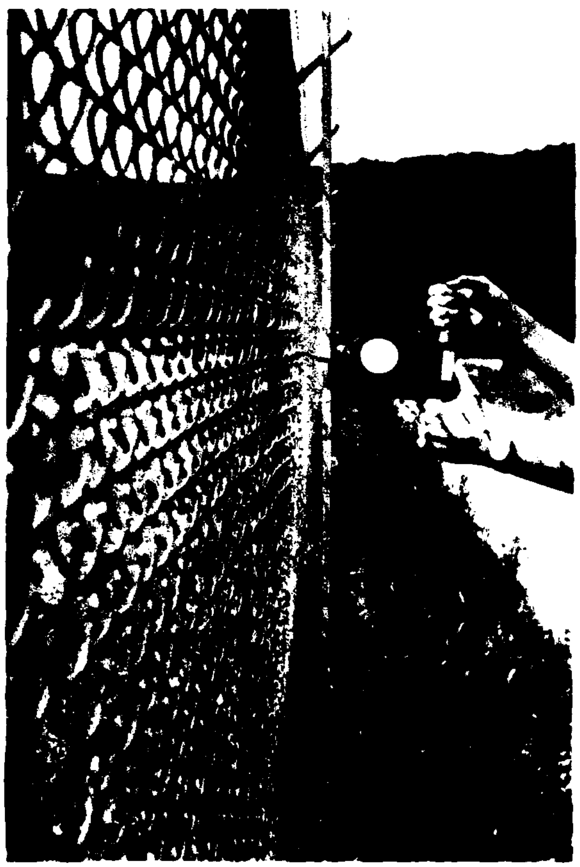
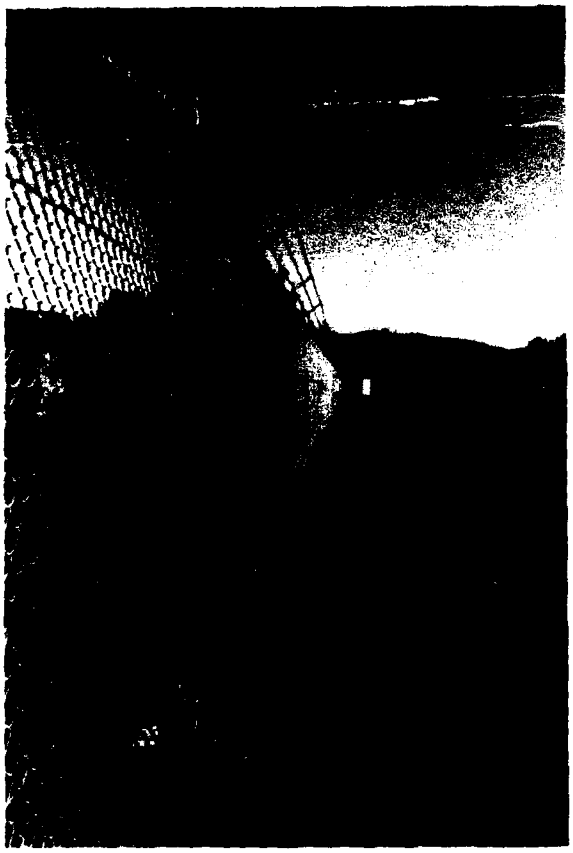


Figure 12. Old CRREL fence.



◀ *a. Prior to normal loading.*

b. Under 132-N normal (pull) load. ▶

Figure 13. SOROIDS fence.

Figure 14. SOROIDS test site, South Royalton, Vermont.

characterization equipment. Table 4 shows variability (the largest minus the smallest of the measured values) between similar panels for the three types of panels: end, corner, and interior. A more complete data breakout can be found in Appendix B.

Operation time using the prototype characterization equipment was 12 minutes per panel with one person making measurements and one person recording the data. Some problems were encountered that will require minor modifications, but the overall concept—obtaining quantitative determinations of fence quality using standard techniques and equipment—proved valid. Proposed modifications for a second-generation testing kit are given in Appendix C. These modifications will allow measurements to be taken by one person.

Because the fence fabric was flexed prior to measuring normal displacement, those measurements were repeatable on a given day. Measurements of all parameters over a period of time were expected to show variation due to effects such as thermal expansion and contraction of the fence fabric. The data obtained with duplicate measurements on a particular day were not recorded in quantitative form; instead, a notation of 'no change' was made.

Climber tests

The final verification of the validity of the fence characterization equipment was to check if there was a correlation between the fence fabric and post deflection in relation to an intruder or climber and the values

Table 4. Variability of fence characteristics.

Fence location	*Fabric* Normal* displacement	*Fabric* Transverse stiffness: Horizontal	*Fabric* Transverse stiffness: Vertical	*Post* Plumbness angle	*Post* Rigidity**
End	22.4 mm	0†	0†	0°	2 mm
Corner	3.2 mm	59 N	34 N	1.5°	2 mm
Interior	38 mm	100 N	100 N	0.7°	2 mm

†For both measurements of transverse stiffness, the fabric of the end panels did not separate prior to or at a load of 118 N.
*132 N applied load.
**226 N applied load.

Table 5. Deflections normal to the fence due to stationary climbers.

	Post				Panel			
	Hands		Feet		Hands		Feet	
Fence location	*75 kg**	*45 kg*	*75 kg*	*45 kg*	*75 kg*	*45 kg*	*75 kg*	*45 kg*
CRREL (Old)	7	5	15	10	53	25	76	55
CRREL (New)	17.5	5	15	11	12.5	20	62.5	20
SOROIDS	13	9	12	7	76	51	76	38

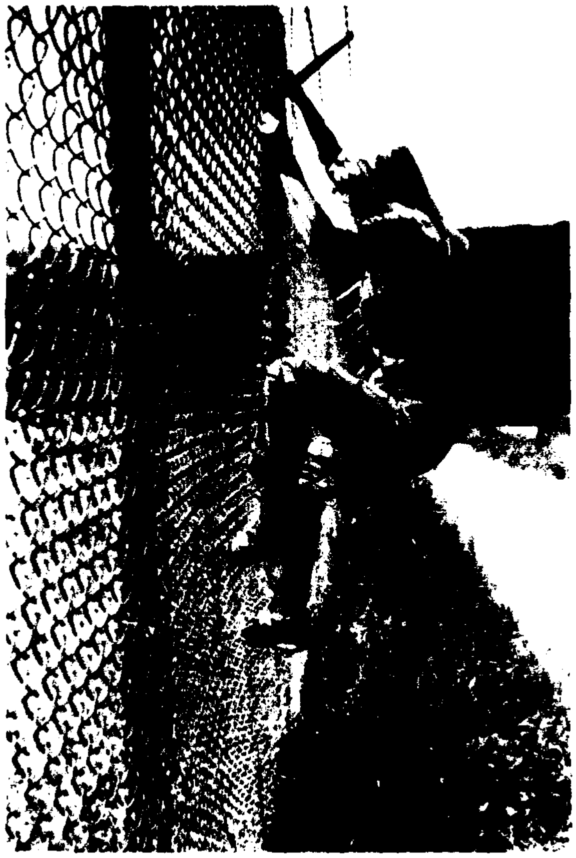
*Climber weights: 45 kg and 75 kg.
Deflections in millimeters. The fence fabric would displace toward the intruder at the hand positions and away from the intruder at the feet positions.

obtained using the characterization equipment. For this test, one mid-fence panel at SOROIDS was chosen as well as the previous test panels at the two CRREL locations. The human climbers were positioned halfway up the post or panel and deflections at the hand and foot positions measured. A compendium of these data appears in Table 5. Figure 15 shows typical fence deflections due to an intruder at the three locations.

The fence deflections at the posts are quite similar for each of the two climbers. The panel deflections show

a. Panel, new CRREL fence. *b. Post, new CRREL fence.*

Figure 15. Deflections due to 45-kg intruder.



c. Panel, old CRREL fence. ▶

◀ *d. Post, old CRREL fence.*

Figure 15 (cont'd).

◀ e. Panel, SOROIDS fence.

f. Post, SOROIDS fence. ▶

Figure 15 (cont'd).

more variability. On the old CRREL fence, the load imparted by each climber was such that the deflection of the fence was 1.5–2 times greater at the foot position than it was at the hand grip. The "give" of the panel of the new CRREL fence was such that the lighter-weight climber displaced the fabric equally at the hand and foot positions, while the heavier climber displaced the fence predominantly with his feet (5 times larger displacement than at the hand grip). The reverse occurred with the climbers on the SOROIDS fence panel: the heavier climber caused equal displacements at the hand and foot positions while the lighter climber displaced the fabric more at the hand grip than at the foot position. Some of this variability is due to the differing climbing postures where the measurements were taken on the panels (i.e., the same climber did not duplicate his or her stance on all three fences). Most of the variability among deflections caused by the same climber on the three fences is probably directly attributable to the differences in fabric stiffness, post plumbness and post rigidity among the fences. The deflections caused by the climbers at a particular post or panel differ due to weight and strength differences between the climbers.

CONCLUSIONS AND RECOMMENDATIONS

Parameters that denote the condition of a galvanized-steel chain-link fence and consequently a fence's suitability for use with a fence-mounted IDS have been identified. A prototype evaluation kit for measuring these parameters was designed at CRREL and field tested for ease of use and applicability. Further development work is necessary to facilitate use of the kit. Otherwise, the equipment successfully measured the necessary parameters with short-term repeatable results. A suggested inspection procedure and schedule is presented.

During testing of the fence at SOROIDS, the FPS-2 intrusion detection system, a fence-mounted IDS, was triggered by both climbers when they attempted to scale the fence without setting off an alarm. Alarms were triggered both at mid-panel and on the post. As the panel tested was marginally acceptable, the parameter values are conservative and therefore appropriate for determining the suitability of a fence for use with an IDS.

Fence characteristics varied along the SOROIDS fence sufficiently to justify the testing pattern devised (ends, adjacent corner panels, and every fifth panel otherwise). Transverse stiffness did not prove to be as important as originally thought, as it is not directly relatable to the normal stiffness. In addition, tranverse stiffness varies widely along a single panel, in some places tight, in others the links not touching. The irregularity in contact between links probably has its origin in the manufacture of the fabric or in the installation procedure. Link separation due to ground surface irregularity can be ruled out because the ground was leveled prior to the erection of the fence, so that any nonuniformity in elevation along the fence would be insufficient to distort the fence fabric.

The instrumentation designed to characterize the fence proved workable in field tests. Average panel characterization time was approximately 12 minutes on the first trial. Increased use and familiarity with the equipment will reduce this time. Some further development work on the characterization kit is necessary to reduce weight and to facilitate attachment of the scale and transverse stiffness apparatus to the fence. Replacing the plumb-bob with a digital protractor for the post rigidity and plumbness test will speed the measurement process and enable one person to do the fence characterization alone.

As standardized measurements of the fence parameters discussed here become available, relationships between normal stiffness and transverse stiffness, or between the horizontal and vertical transverse stiffnesses, may become apparent, thus reducing the number of measurements needed to characterize a fence. This should also reduce the panel characterization time. Any such relationships, however, are likely to be highly dependent on the construction, maintenance, and age of a fence, which will probably prevent generalization.

It is proposed that a central data base of IDS performance and corresponding quantitative fence characterization from several facilities be established for referral in the trouble-shooting of fence-mounted IDSs and in the design of IDS security measures. The equipment and test procedures described in this report are proposed as standards for the characterization of chain-link fences.

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APPENDIX A: FENCE INSPECTION PROCEDURE—GALVANIZED STEEL FENCE

I. Visual Inspection (Qualitative)
- A. General Inspection
  1. Catalog loose or moving parts (signs, stiffener clips, etc.)
     - a. Determine if parts are necessary
     - b. Remove unnecessary parts
     - c. Bind down loose critical parts
  2. Remove noise sources, such as debris (brush, trash, etc.)
- B. Posts
  1. Check whether caps are secured to tops of posts
  2. No erosion at bases
  3. Fabric tied to post in at least five equally spaced ($\pm$5-cm) places
- C. Fabric
  1. Check for holes
  2. Bulges (greater than 10 cm)
  3. Stiffeners
     - a. Location
     - b. Attachment to fence
- D. Outriggers
  1. Secured to posts
  2. Barbed tape/wire secured to outriggers
- E. Gates
  1. Check mounting points for secureness
  2. Padlocks, chains, etc., should be secured
  3. Any signs on fence should be securely fastened and not rattle
- F. Recording of Defects
  1. Log nature of defect and location, with sketch
  2. Mark defect on fence (a disadvantage of visually marking defects is that it might attract intruders to weaknesses in the fence)
     - a. Use surveyor's tape
     - b. Mark surveyor's tape with defect log number
     - c. Remove surveyor's tape when defect rectified
- G. Frequency of Inspection
  1. Commensurate with degree of security desired
  2. Minimum of every three months (25% inspection, except gates and corners), with documentation of seasonal variation in fence parameters
  3. Thorough inspection (100%) every twelve months

II. Fence Measurement (Quantitative)
- A. Posts
  1. Tilt
     - a. Measure with plumb bob and ruler
     - b. Measure from 1.5-m height to 0.5 m from ground and record
     - c. Alternative is to use digital protractor 1.5 m from ground.
  2. Rigidity
     - a. Apply 226-N (51-lbf) force-tension or compression, 1.5 m from ground
     - b. Measure angular deflection with digital protractor or measure displacement with scale and plumb bob, while applying force
- B. Fabric
  1. Normal stiffness
     - a. Apply 226-N (51-lbf) push-pull force twice to center of panel
     - b. Apply 132 N (30-lbf) push or pull to fence at center of panel

c. Record deflection

2. Transverse stiffness (optional)

a. Apply 118-N (26-lbf) compressive load horizontally at center of panel

b. Check for link separation

c. Repeat (a) and (b) but in vertical direction

C. Recording of Data

1. Date, time

2. Environmental

a. Air temperature

b. Ground condition (frozen, thawing, dry) and snow depth

3. Fence construction

a. Fabric height, post diameter, post spacing, location and type of stiffeners, spacing and gauge size of panel links

b. Modifications since last measurements taken

c. Post and fabric measurements (location, data)

D. Frequency of Tests

1. 100% inspection before acceptance

2. 10% inspection annually

3. 100% inspection every five years

E. Personnel

1. All measurements can be made by one person

2. Most efficient procedure involves one person making measurements and one person recording data

APPENDIX B: DATA FOR FENCE PARAMETER VARIABILITY

Fence characterization: Inner Fence—Geophysical Sensors Cold Regions Research Facility, South Royalton, Vermont.
Dates: 12 July 1989, 2 August 1989.
Personnel: M.R. Walsh, J.S. Morse, D.J. Lambert, CRREL
Ambient temperature: 24°C
Starting location: South Camera Location

TRANSVERSE STIFFNESS

Numbers (in newtons) denote link separation loads. (118) denotes no separation at 118-N transverse load. Failures: 5 out of 19 panels (26% failure rate).

Panel #	*Horizontal*	*Vertical*	*Panel #*	*Horizontal*	*Vertical*
1	(118)	(118)	30	(118)	(118)
2	(118)	(118)	35	(118)	(118)
5	(118)	(118)	40	(118)	(118)
10	(118)	(118)	45	(118)	(118)
13	(118)	(118)	50	(118)	(118)
14*	(118)	(118)	55	71	62
15*	59	84	60	18	18
16	(118)	(118)	63	80	49
20†	39	98	64	(118)	(118)
25	(118)	(118)			

*Corner Panels.
†Panel used in climbing tests.

NORMAL STIFFNESS

Numbers (in mm) denote scale readings during tests of normal stiffness. Start values are gauge-line positions prior to touching the fence, end values are gauge-line positions with the fabric under load (132 N). Push and pull denote a normal load directed away from or toward the person applying the load. Ends and corner measurements taken while pushing due to interference from bracing wires. Failures: none in 19 tested panels.

Panel #	*Start*	*End*	Δ	*Push/Pull*	*Panel #*	*Start*	*End*	Δ	*Push/Pull*
1	57.2	108	50.8	Push	30	139.6	101.6	38.0	Pull
2	146	79.4	66.6	Pull	35	139.6	98.4	41.2	Pull
5	142.8	79.4	63.4	Pull	40	139.6	95.2	44.4	Pull
10	136.6	87.8	50.8	Pull	45	142.8	88.8	54.0	Pull
13	139.6	76.2	63.6	Pull	50	146	88.8	57.2	Pull
14	73	120.6	47.6	Push	55	130.2	69.8	60.4	Pull
15	76.2	127	50.8	Push	60	142.8	73	69.8	Pull
16	139.6	79.4	60.2	Pull	63	142.8	73	69.8	Pull
20	139.6	63.6	76.9	Pull	64	51.2	130.2	73.2	Push
25	127	73	54.0	Pull					

POST RIGIDITY

Deflection (in mm) at 1.5-m height with 226-N force. Failures: None in 19 tested posts.

Panel no.	*Deflection*	*Panel no.*	*Deflection*
1*	2	30	4
2	5	35	4
5	5	40	4
10	6	45	5
13	5	50	5
14†	6	55	4
15†	4	60	5
16	6	63	6
20**	4	64*	4
25	5		

*End panels.
**Panel used in climbing tests.
†Corner panels.

POST PLUMBNESS

Measurements (in mm) taken using 1.5-m plumb line. The difference is (base-top). Tilt angles are calculated as $\tan^{-1}$ *(Δ/1500).*

Panel no.	*Top*	*Mid*	*Base*	Δ	*Angle*
1	91	86	80	−11	−0.4°
2	78	75	80	2	0.1°
5	78	78	79	1	0°
10	78	74	68	−10	−0.4°
13	78	73	70	−8	−0.3°
14	78	72	68	−10	−0.4°
15	80	91	110	30	1.1°
16	79	77	75	−4	−0.2°
20	78	75	72	−6	−0.2°
25	78	73	67	−11	−0.4°
30	78	74	70	−8	−0.3°
35	78	72	67	−11	−0.4°
40	78	77	73	−5	−0.2°
45	78	79	78	0	0°
50	79	79	79	0	0°
55	78	75	73	−5	−0.2°
60	78	71	64	−14	−0.5°
63	78	72	63	−15	−0.6°
64	78	74	68	−10	−0.4°

APPENDIX C: PROPOSED MODIFICATIONS TO FENCE CHARACTERIZATION KIT

After field trials by three individuals, the following suggestions were made for improving the prototype characterization kit. These changes should make the kit lighter and easier to use, thus reducing the time required to survey a fence. Modifications are broken down as they pertain to separate kit components.

1. Fence fabric normal stiffness—fabric side (see Fig. 2).
   a. Replace force gauge with smaller, lighter weight model.
   b. Make standoffs spring-loaded for easier mounting. Replace disks with hooks.
   c. Spring-load scale mount. May want to use scale with black background and white graduations and numbers.
   d. Replace loose stainless gauge line with a roll-up line device, such as used for chalk lines.

2. Fence fabric normal stiffness—post side (see Fig. 3).
   a. Use smaller magnetic stands for standoffs.
   b. See a, c & d above.

3. Fence fabric transverse stiffness (see Fig. 8a).
   a. Replace mounting disks with a hook arrangement.
   b. Add Teflon tape between sliding components.

4. Post rigidity (see Fig. 9)
   a. See 1(a) for force gauge
   b. See 1(b) and 2(b) for standoffs
   c. Use digital protractor rather than plumb bob.

5. Post plumbness (see Fig. 10a)
   a. See 1(b) and 2(b) for standoffs
   (Fabric side standoff not shown in Figure 10a. Use of digital protractor may give false readings in case of bowed or bent post.)
   b. See 4(c).

6. Packaging
   A foam-filled fiberglass carrying case has been ordered for ease of transporting equipment. At the time of this report, the case had not been received and thus no photograph of the completed kit is available.

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13. ABSTRACT (*Maximum 200 words*)

Equipment and test procedures for quantifying the normal stiffness, transverse stiffness, post rigidity and post plumbness of a chain-link fence are described. These parameters characterize the condition of the fence and determine its suitability for use with a fence-mounted intrusion detection system.

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